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Specifics of drives functioning in main mechanisms of open-pit excavator

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Abstract. Specifics of functioning for the drives of main (lifting and thrusting) mechanisms in an open-pit excavator were determined for their joint action during the process of excavation. It was shown that the operation forms a two-crank lever-age transmission mechanism (connecting the main mechanisms and the excavator bucket) and a common transmission mechanism of the drives (consisting of the main mechanisms and the leverage). It was also established that an initial link of the common transmission mechanism would be a «stick-bucket» link whose co-ordinates determine positions of every other link in the mechanism in relation to the stand (a boom). Dependencies were derived for finding kinematic transfer functions of the leverage, that is relations between lifting and thrusting velocities and an excavation velocity when the bucket (its cutting edge) is moved along a given trajectory in the process of pit development. The results of the research could be used for the purposes of designing a control system for the main drives of an excavator.

1. Introduction

Efficiency of functioning in the case of an open-pit excavator is mainly determined by how well its working motions are coordinated while lifting and thrusting mechanisms join in the process of rock excavation.

The excavation is carried out by matching workings of the main mechanisms of an excavator (mechanisms of lifting and thrusting) aimed at moving its bucket forward and up while at the same time extracting a layer of rock hindered and limited by constantly changing operational conditions and psychophysical capacities of an excavator operator. As practice of using open-pit excavators shows, the duration of a working cycle under specific conditions greatly exceeds a calculated time.

All in all, the present day of market economy dictates the necessity of taking certain measures whose goal would be to increase the efficiency of using technological capabilities of an open-pit excavator. One of the main directions in solving that problem deals with analyzing how the main mechanisms move during the excavation. Known methods of determining the laws of motion for such mechanisms are based on some formal approaches – fuzzy logic, artificial intelligence and so on [1-5].

2. Goal of the research

The goal of this research is to find kinematic and dynamic characteristics of the excavation process by determining how operation parameters of the main mechanisms (lifting and thrusting velocities)



change while ensuring that the excavator bucket (top of its cutting edge) moves along a specified trajectory.

The tasks include:

- justification of a mathematical model for a transmission mechanism formed in the process of excavation;
- determination of such lifting and thrusting velocities which enable the movement of the bucket (top of the cutting edge) along the given path.

The object of the research is a mechanical system which consists of the main (lifting and thrusting) mechanisms and transmission mechanism. The subject is to establish functional dependencies between those parameters which determine the position of the bucket (its cutting edge) within a pit and operation parameters of the main mechanisms (velocities of lifting and thrusting). And the methods used are adopted from the theory of machines and mechanisms, mathematical modelling and computational experimenting.

3. Solution of the goal

A structural analysis was carried out on a kinematic chain formed due to joint action of mining (lifting and thrusting) mechanisms. The chain consists of driven links of the main mechanisms (a rack gear of the thrusting mechanism, a head block of the boom, a fragment of the lifting rope coming off the head block) and elements of the operational equipment (a saddle bearing, stick, bucket rigidly fastened to the stick and bucket suspension) (Fig. 1).

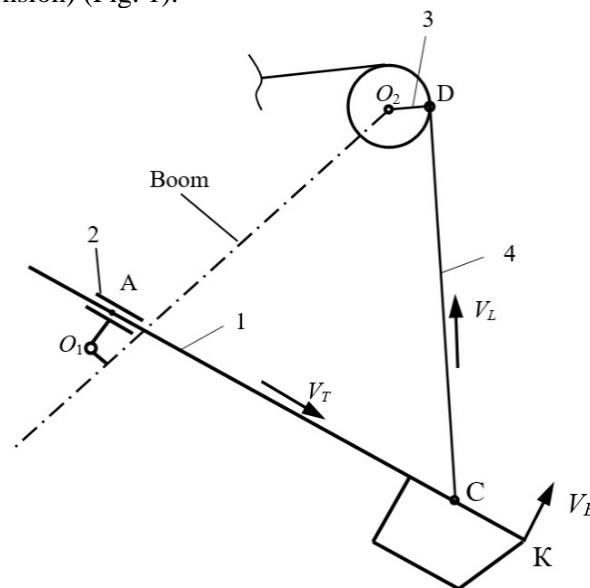


Figure 1. Schematics of kinematic chain: 1 – «stick-bucket» link; 2, 3 – crank; 4 – lifting rope; V_E , V_L , V_T – velocities of excavation, lifting, thrusting.

The following assumptions were made:

- the head block of the boom is in fact a driven link of the lifting mechanism since the velocity at that point where the rope comes off the block equals the lifting velocity and, kinematically, is a crank;
- the lifting rope (or rather its fragment) is a weightless inextensible string in the form of a variable-length rod;
- the suspension, articulated to the bucket, forms a common rod with the rope.

The structural analysis of the kinematic chain resulted in the following statements:

- a kinematic pair formed by the rope and head block has a relative equivalence to the velocity of a revolute pair (hinge), which is momentary in this case;
- a «stick-bucket» link forms a two-degrees-of-freedom linkage with the stand (boom) in the form of a translational pair (stick-saddle bearing) and revolute pair (saddle bearing-boom);

- the kinematic chain includes four movable links: the two cranks (rack gear and head block), rod (lifting rope and bucket suspension) and «stick-bucket» link;
- the chain forms with the stand (boom) a two-crank leverage mechanism.

Thus, a leverage transmission mechanism is formed in the process of excavation, which converts motions of the driven links of the main mechanisms into the motion (movement) of the bucket [6].

Degrees of freedom (mobility) for such a transmission mechanism could be calculated as

$$S = 3n - 2P_5 = 3 \cdot 4 - 2 \cdot 5 = 2,$$

where $n = 4$ is the number of pairs of movable links; $P_5 = 5$ – the number of fifth-class (one-degree-of-freedom) pairs.

A mechanism with two degrees of freedom (two generalized coordinates) could have either two initial links (if coordinates of two links are generalized) or one initial link (if it forms a two-degrees-of-freedom pair with the stand) [7,8].

The «stick-bucket» link is assumed to be an initial one, and, therefore, positions of all links, both in the transmission mechanism and main mechanisms, would be determined by the position of the «stick-bucket» link. Thus, the process of excavation is characterized by formation of a common transmission mechanism of the main drives which includes the main mechanisms and transmission mechanism (Fig. 2).

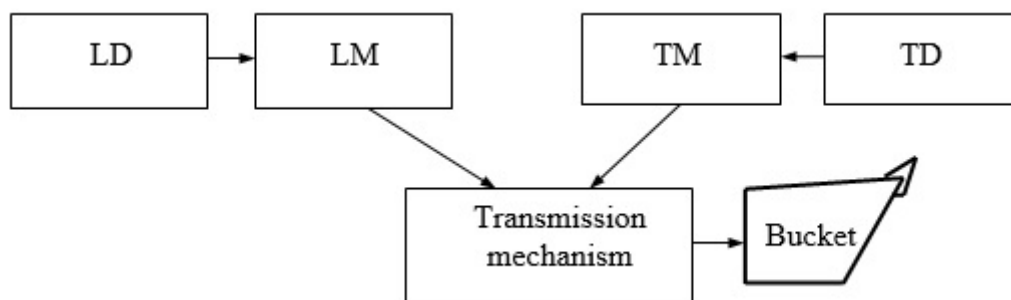


Figure 2. Structural schematics of electro-mechanical system in open-pit excavator: LD, TD – drives of lifting (LM) and thrusting (TM) mechanisms.

The generalized coordinates of the common transmission mechanism is defined by coordinates of the bucket's cutting-edge top – point K (X_K and Y_K) in the XOY coordinate system, where the OX axis matches the datum level of an excavator, and the OY axis – the rotation axis of its revolving platform. The transmission mechanism was kinematically analyzed using a grapho-analytical method by plotting diagrams of the mechanism and its velocities.

In general, leverage mechanisms differ from other mechanisms by having «individual» kinematic properties which depend on a structural schematic of the mechanism, the type of kinematic relations between its links and geometric parameters (lengths) of those links. First and foremost, a leverage is characterized by kinematic and dynamic transfer functions (gear ratios) which define dependencies between kinematic and dynamic parameters of driven and driving links [9-12].

To determine the velocities of working (lifting and thrusting) motions, it is necessary to specify the laws of movement for the initial link, that is a trajectory of bucket (top of the cutting edge) movement and the excavation velocity along with dimensions of the transmission links. Since the thrusting velocity changes direction relative to the bucket position in a pit, then, therefore, the form of a velocity vector graph and the type of dependencies for calculating the velocities of working motions change, too (Fig. 3, 4).

Based on a mathematical model of the transmission mechanism, expressions were obtained for finding such velocities of lifting and thrusting motions which would provide a proper movement of the bucket along a specified trajectory. The dependencies to determine the kinematic transfer functions

(relations between the velocities of lifting V_L and thrusting V_T and the excavation velocity V_E) could be expressed in their general forms as:

$$KTF_T = \frac{V_T}{V_E} = f_1(X_K, Y_K, l_i, \psi, \alpha_i);$$

$$KTF_L = \frac{V_L}{V_E} = f_2(V_T, X_K, Y_K, l_i, \psi, \alpha_i),$$

where KTF_T , KTF_L are kinematic transfer functions of thrusting and lifting motions; l_i – lengths of links; ψ – inclination of a tangential trajectory for the bucket movement at the point K ; α_i – angles determining positions of the links.

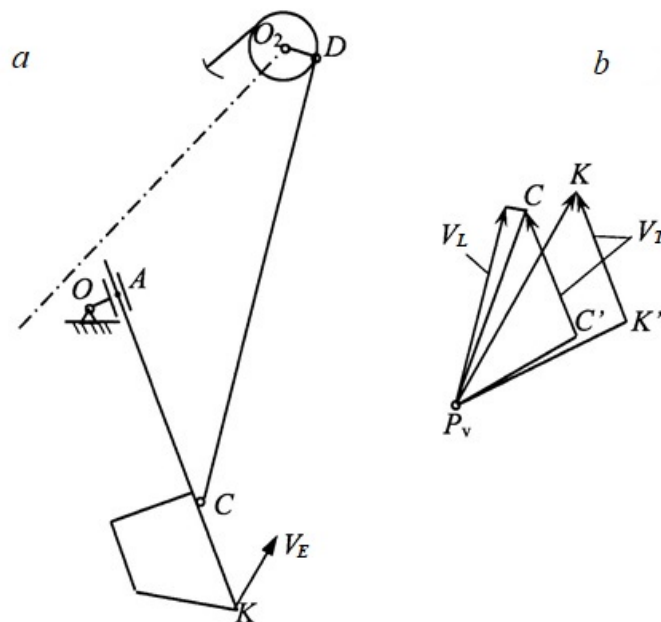


Figure 3. Diagrams of mechanism (a) and velocities (b) for a bucket in the bottom section of a pit.

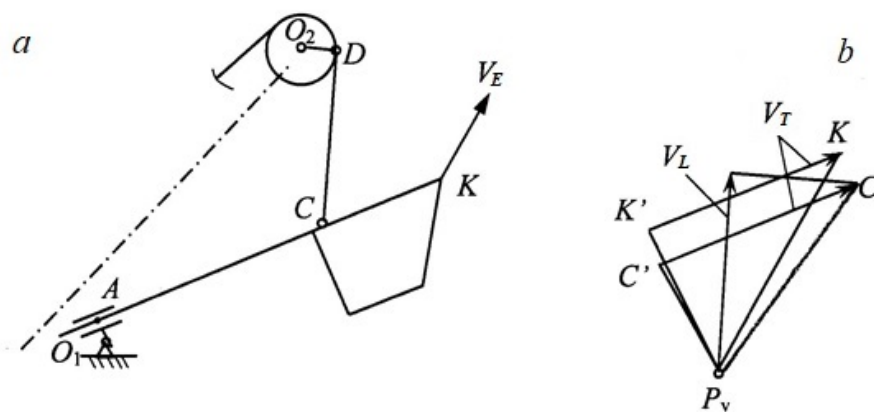


Figure 4. Diagrams of mechanism (a) and velocities (b) for a bucket in the top section of a pit.

A computational experiment was carried out to calculate operation parameters of the main mechanisms for an EKG-20A excavator made by JSC «Uralmashplant». Initial data for the calculation were taken as: tangent force of resistance to excavation $P_{01} = 325 \text{ kN}$; excavation velocity $V_E = 1 \text{ m/s}$; bucket mass $M_B = 40 \text{ tn}$.

Fig. 5 and 6 show graphs for the lifting and thrusting velocities while moving the bucket within a pit of 17 m in height.

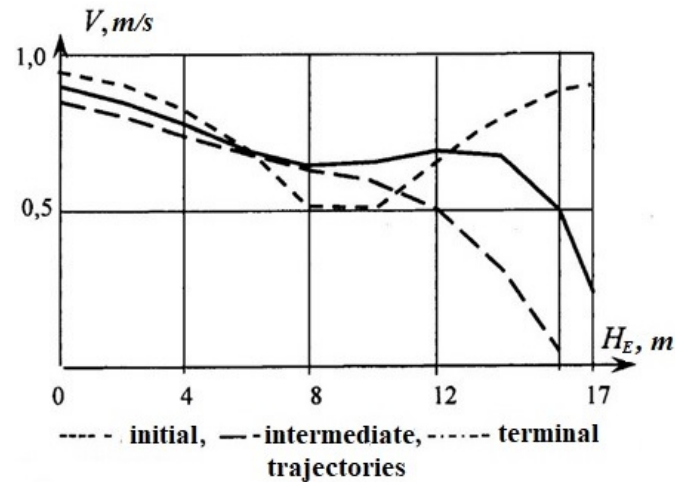


Figure 5. Graphs of relations between lifting velocity and excavation height.

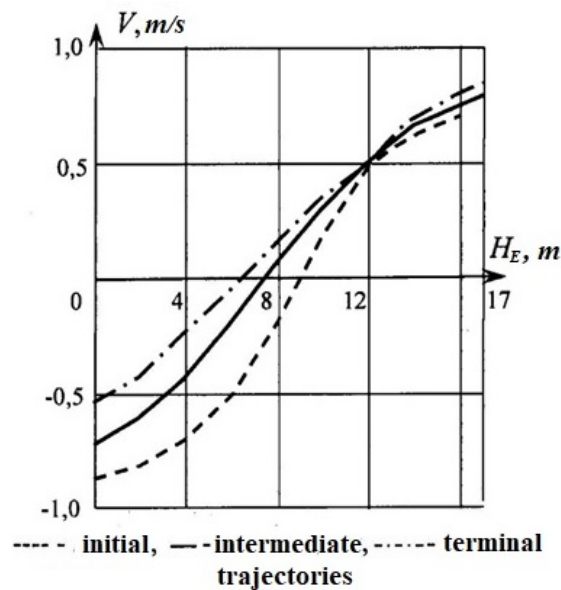


Figure 6. Graphs of relations between thrusting velocity and excavation height.

An optimizing algorithm was developed to control the working process of an open-pit excavator and realize required values of the operation parameters of its main mechanisms while moving the bucket with a set excavation velocity within its work area. The algorithm defines the content and sequence of the following operations which enable the movement of the bucket along a specified path:

- computing the velocities of lifting and thrusting at an initial position of the bucket and positions which follow and correspond to moving the bucket with a given step;
- evaluating the velocities at three positions (initial, intermediate and terminal) and transmitting commands proportional to those values to the input of the control system for the drives of the main mechanisms;
- moving the bucket to the following position.

A simulation model was built for the process of rock excavation using the operational equipment of a front-shovel open-pit excavator. It represents such a set of calculated values for operation parameters

of the main mechanisms which ensures that the bucket moves along a specified trajectory and with given energy-force parameters realized on the bucket. The model defines an overall algorithm of digital control to form control actions sent to the drives of the main mechanisms [13-17].

Thus, the simulation model of excavation obtained from the computational experiment allows to determine required operation parameters for the main mechanisms of an excavator at any point within its work area for given energy-force parameters realized on the bucket and a specified trajectory of bucket (top of the cutting edge) movement.

4. Conclusion

The suggested methodology of calculating, via a computational experiment, operation parameters (lifting and thrusting velocities) for the main mechanisms of open-pit excavators allows to determine actual values for the velocities of their working motions under specific mining and technological conditions of operation (dimensions of a pit, type of the trajectory for bucket movement, etc.).

Finding correlations between the operation parameters during excavation could serve as a basis for developing an adaptive system of digital control for the drives of the main mechanisms of an excavator which would increase the efficiency of its functioning due to proper coordination of the lifting and thrusting velocities under specific conditions of operation.

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